CTD Calibration Report for R/V Oceanus 411-1
prepared by Margaret Cook
Woods Hole Oceanographic Institution

I.1 Cruise Summary

Ship: R/V Oceanus 411-1
Project Name: Site W
Dates: 26 April 2005 – 04 May 2005
Ports: Woods Hole – Woods Hole

22 CTD stations
Rosette salts and dissolved oxygen

I.2 Digital data files included as part of this distribution:

2005apr_ctd_proc.doc This document in MS-Word format.
2005apr_ctd_proc.pdf *T*his document in pdf format.

OC411_CTD_stationlog.doc At sea station by station event log

2005apr.whp_btl This file follows WOCE specifications for bottle data.
Salt and oxygen quality words have been entered.

2005apr.sum The SUM file contains the CTD station information using WOCE format.

2005apr_*.ctd One 2db averaged file per station following the WOCE format specification for CTD profiles. The final *.CTD files contain primary conductivity and secondary oxygen data. All CTD salt and oxygen data have been calibrated to the bottle salt and oxygen data. CTD temperatures have been scaled with pre-cruise calibrations. CTD pressures have been scaled with pre-cruise calibrations.

II. Finalized Description of Measurements

II.1 CTD Measurements

Twenty two casts were made using a SeaBird 911plus CTD configured to measure pressure, temperature, conductivity, and oxygen current. For each cast, water samples were collected at discrete intervals and analyzed for salinity and dissolved oxygen – primarily for the purpose of calibrating the CTD sensors. All casts were full water column.

II.1.a Difficulties Encountered

- There were no difficulties which impaired data collection or processing during this cruise.

II.1.b Equipment Configuration

A SeaBird 911plus CTD (serial number 0462) was used throughout the cruise. It was provided with a Digiquartz TC pressure transducer S/N 63505, two temperature sensors

S/N 032271 and S/N 032900, two conductivity sensors S/N 041860 and S/N 042147, and two SBE43 oxygen sensors S/N 0820 and S/N 0072. Calibrations for all CTD sensors were performed by the manufacturer before the cruise. The CTD was also provided with a Wetlab ECO-AFL/FL flourometer (S/N 013), a Wetlab ECO-AFL Flourometer (S/N 013), an OBS Seapoint Turbidity meter (S/N 1661), and an altimeter (S/N 997).

CTD data from both the primary and the secondary conductivity and oxygen sensors were calibrated for the entire cruise. However, primary conductivity and secondary oxygen were chosen for the final WOCE format *.CTD data files due to their superior performance.

The pylon was controlled through a dedicated personal computer using SeaBird's software SEASOFT version 5.33 for windows. A rosette frame was provided for the cruise. The frame held 22 10-liter bottles some of which were produced at WHOI and some which were borrowed from Scripts Institute of Oceanography.

II.1.c Acquisition and Processing Methods

Data from the CTD were acquired at 24 hz. The CTD data were acquired by an SBE Model 11 plus CTD Deck Unit providing demodulated data to a personal computer running SeaBird software. SEASAVE version 5.33 CTD acquisition software (SeaBird) provided graphical data to the screen. Bottom approach was controlled by real time altimeter data and ship provided ocean depth information.

After each station, the raw CTD data was run through the SeaBird data conversion software listed in Table 2. The data was first-differenced, lag corrected, pressure sorted and centered into 2 decibar bins for final data quality control and analysis.

Table 2. SeaBird Processing Software

SeaBird Module	Description (SeaBird, Version 5.33)
DATCNV	Convert the raw data to pressure, temperature, conductivity, and dissolved oxygen current.
ROSSUM	Reads in a .ROS file created by DATCNV and writes out a summary of the bottle data to a file with a .BTL extension.
ALIGNCTD	Advance conductivity approximately 0.073 seconds relative to pressure.
WILDEDIT	Checks for and marks and 'wild' data points: first pass 2.0 standard deviations; second pass 20 standard deviations.
CELLTM	Conductivity cell thermal mass correction alpha = 0.03 and 1/beta = 7.0.
FILTER	Low pass filter conductivity with a time constant of approximately 0.03 seconds. Filter pressure with a time constant of 0.15 seconds to increase pressure resolution for LOOPEDIT.
LOOPEDIT	Mark scans where the CTD is moving less than the minimum velocity (0.1 m/s) or traveling backwards due to ship roll.
DERIVE oxy.cfg	Compute oxygen from oxygen current, temperature, and pressure.
BINAVG	Average data into the 2 dbar pressure bins.
DERIVE sal.cfg	Compute salinity.
STRIP	Extract columns of data from .CNV files.
TRANS	Change .CNV file format from ASCII to binary.
SPLIT	Split .CNV file into upcast and downcast files.

Standard final output included the following variables:

```
# name 0 = prDM: Pressure, Digiquartz [db]
# name 1 = t090C: Temperature [ITS-90, deg C]
# name 2 = t190C: Temperature, 2 [ITS-90, deg C]
# name 3 = c0mS/cm: Conductivity [mS/cm]
# name 4 = c1mS/cm: Conductivity, 2 [mS/cm]
# name 5 = sbeox0V: Oxygen Voltage, SBE 43
# name 6 = sbeox0dOC/dT: Oxygen, SBE 43 [doc/dt]
# name 7 = scan: Scan Count
# name 8 = sbeox0ML/L: Oxygen, SBE 43 [ml/l]
# name 9 = sbeox1V: Oxygen Voltage, SBE 43, 2
# name 10 = sbeox1dOC/dT: Oxygen, SBE 43, 2 [doc/dt]
# name 11 = sbeox1ML/L: Oxygen, SBE 43, 2 [ml/l]
# name 12 = oxsatML/L: Oxygen Saturation [ml/l]
# name 13 = oxsatML/L: Oxygen Saturation [ml/l]
# name 14 = nbin: number of scans per bin
# name 15 = sal00: Salinity [PSU]
# name 16 = sal11: Salinity, 2 [PSU]
# name 17 = flag: flag
```

CTD salinity and oxygen data were then calibrated by fitting the data to water sample salinity and oxygen data. WHOI post-processing fitting procedures are modelled after Millard and Yang, 1993.

A second set of CTD data files used for LADCP processing were also created using a subset of the Seabird data conversion software liseted in Table 2.
Standard final output included the following variables:

```
# name 0 = timeS: Time, Elapsed [seconds]
# name 1 = prDM: Pressure, Digiquartz [db]
# name 2 = t090C: Temperature [ITS-90, deg C]
# name 3 = c0mS/cm: Conductivity [mS/cm]
# name 4 = sal00: Salinity [PSU]
# name 5 = svCM: Sound Velocity [Chen-Millero, m/s]
# name 6 = timeJ: Julian Days
# name 7 = latitude: Latitude [deg]
# name 8 = longitude: Longitude [deg]
# name 9 = scan: Scan Count
# name 10 = t190C: Temperature, 2 [ITS-90, deg C]
# name 11 = c1mS/cm: Conductivity, 2 [mS/cm]
# name 12 = sal11: Salinity, 2 [PSU]
# name 13 = svCM1: Sound Velocity, 2 [Chen-Millero, m/s]
# name 14 = nbin: Scans Per Bin
# name 15 = flag:
```

II.1.d Summary of manufacture CTD Calibrations

All sensors were calibrated by the manufacturer. A listing of sensors and calibration dates are presented in Table 3.

Table 3. Sensor Calibration Dates.

Sensor Number	Sensor Type	Manufacturer	Calibration Dates
63505	pressure	Paroscientific/Sea-Bird	23 Dec 2002
032271	temperature	Sea-Bird	24 Feb 2005
032900	temperature	Sea-Bird	19 Feb 2005
041860	conductivity	Sea-Bird	17 Feb 2005
042147	conductivity	Sea-Bird	17 Feb 2005
0820	SBE43 dissolved oxygen	Sea-Bird	16 Apr 2005
0072	SBE43 dissolved oxygen	Sea-Bird	16 Apr 2005

II.1.e Summary of CTD Calibrations

PRESSURE CALIBRATION

The pressure bias of the CTD at the sea surface was monitored at the beginning of each station to make sure there was no significant drift in the calibration. On deck pressure bias ranged from 0.2 to 0.7 decibars.

CONDUCTIVITY CALIBRATION

Basic fitting procedure:

The CTD primary and secondary conductivity sensor data were fit to the water sample conductivity. All stations were grouped together in chronological order to find the best fit. The group was fit for slope and bias. A linear pressure term (modified beta) was applied to conductivity slopes using a least-squares minimization of CTD and bottle conductivity differences. The function minimized was:

$$BC - m * CC - b - \beta * CP$$

where BC - bottle conductivity [mS/cm]
CC - pre-cruise calibrated CTD conductivity [mS/cm]
CP - CTD pressure [dbar]
m - conductivity slope
b - conductivity bias [mS/cm]
? - linear pressure term [mS/cm/dbar]

The slope term is a polynomial function of the station number based upon chronological station collection order. The polynomial function which provided the lowest standard deviation for a group of samples along with the corresponding bias were determined for each station grouping. A series of fits were made, each fit removing outliers having a residual greater than three standard deviations. This procedure was repeated with the remaining bottle values until no more outliers occurred. The best fit coefficients for each station grouping are presented in Table 4a for primary sensor 041860 and secondary sensor 042147. Fits to primary conductivity and temperature were applied to the final data.

The final conductivity, FC [mS/cm] is:

$$FC = m * CC + b + \beta * CP$$

Data Quality

Calibrated, the overall standard deviation of the CTD conductivity and the water sample differences for primary sensor (S/N 041860) is **0.0006838**. The overall standard deviation for secondary conductivity sensor (S/N 042147) and the water sample differences is **0.0007531.**

Table 4a. Best Fit Conductivity Coefficients for Primary Conductivity S/N 041860

Stations	**#pts used**	**total #pts**	**std dev (mS/cm)**	**Slope**	**Bias**	**Beta**
Fit as a group in chronological order [1:12 14:22 13]	337	376	.0006838			
1				0.99999296	0.00094236	-2.52499041e-07
2				1.00000314	0.00094236	-2.52499041e-07
3				1.00001451	0.00094236	-2.52499041e-07
4				1.00002487	0.00094236	-2.52499041e-07
5				1.00003287	0.00094236	-2.52499041e-07
6				1.00003785	0.00094236	-2.52499041e-07
7				1.00003974	0.00094236	-2.52499041e-07
8				1.00003889	0.00094236	-2.52499041e-07
9				1.00003599	0.00094236	-2.52499041e-07
10				1.00003196	0.00094236	-2.52499041e-07
11				1.00002777	0.00094236	-2.52499041e-07
12				1.00002439	0.00094236	-2.52499041e-07
13				1.00002547	0.00094236	-2.52499041e-07
14				1.00002267	0.00094236	-2.52499041e-07
15				1.00002322	0.00094236	-2.52499041e-07
16				1.00002629	0.00094236	-2.52499041e-07
17				1.00003172	0.00094236	-2.52499041e-07
18				1.00003880	0.00094236	-2.52499041e-07
19				1.00004619	0.00094236	-2.52499041e-07
20				1.00005186	0.00094236	-2.52499041e-07
21				1.00005295	0.00094236	-2.52499041e-07
22				1.00004573	0.00094236	-2.52499041e-07

Table 4b. Best Fit Conductivity Coefficients for Secondary Conductivity S/N 042147

Stations	#pts used	total #pts	std dev (mS/cm)	Slope	Bias	Beta
Fit as a group in chronological order [1:12 14:22 13]	339	375	.0007531			
1				1.00014640	-0.00547719	1.59155491e-08
2				1.00015536	-0.00547719	1.59155491e-08
3				1.00016901	-0.00547719	1.59155491e-08
4				1.00018364	-0.00547719	1.59155491e-08
5				1.00019668	-0.00547719	1.59155491e-08
6				1.00020655	-0.00547719	1.59155491e-08
7				1.00021252	-0.00547719	1.59155491e-08
8				1.00021456	-0.00547719	1.59155491e-08
9				1.00021319	-0.00547719	1.59155491e-08
10				1.00020933	-0.00547719	1.59155491e-08
11				1.00020415	-0.00547719	1.59155491e-08
12				1.00019895	-0.00547719	1.59155491e-08
13				1.00021222	-0.00547719	1.59155491e-08
14				1.00019497	-0.00547719	1.59155491e-08
15				1.00019329	-0.00547719	1.59155491e-08
16				1.00019463	-0.00547719	1.59155491e-08
17				1.00019925	-0.00547719	1.59155491e-08
18				1.00020676	-0.00547719	1.59155491e-08
19				1.00021603	-0.00547719	1.59155491e-08
20				1.00022497	-0.00547719	1.59155491e-08
21				1.00023045	-0.00547719	1.59155491e-08
22				1.00022811	-0.00547719	1.59155491e-08

OXYGEN CALIBRATION

Basic fitting procedure

The CTD oxygen sensor variables were fit to water sample oxygen data to determine the six parameters of the oxygen algorithm (Millard and Yang, 1993). The oxygen calibration was performed after calibrating temperature and conductivity due to its weak dependence on the CTD pressure, temperature, and conductivity (salinity). A FORTRAN program oxfitmrx.exe developed by Millard and Yang (1993) was encorporated into matlab routines by Millard (2004) for use in processing ctd oxygens using matlab. The following matlab mfiles created by Jane Dunworth were used for determining and applying the oxygen calibration coefficients using Millard's routines: make_oxygile.m, oxycal_SBE.m, plot_caloxy.m, claoxy_dco.m, plot_thetaso.m, dco2ctd.m, cal_nut.m, cnut_2_ctd.m. These programs used the following algorithm developed by Owens and Millard (1985) for converting oxygen sensor current and temperature measurements with the time rate of change of oxygen current measurements to oxygen concentration. The weight was set to 0 as the new SBE43 oxygen sensor temperature is not measured and is assumed to be the same as the in situ temperature. The lag was set to 0 as per manufacturer recommendation.

$$Oxm = \left[slope * \left(Oc + lag * \tfrac{dOc}{dt}\right) + bias\right] * Oxsat * \exp\left(tcor * \left[T + wt * \left(T_o - T\right)\right] + pcor * P\right)$$

where	Oxm	- oxygen concentration [ml/l]
	Oc	- oxygen current [uA/s]
	Oxsat	- oxygen saturation []
	P	- CTD pressure [dbar]
	T	- CTD temperature [°C]
	T_o	- oxygen sensor temperature [°C]
	S	- salinity [PSS-78, psu]
	slope	- oxygen current slope []
	lag	- oxygen sensor lag [s]
	bias	- oxygen current bias []
	tcor	- membrane temperature correction []
	wt	- weight, membrane temperature sensitivity adjustment []
	pcor	- correction for hydrostatic pressure effects

Data from all stations and both oxygen sensors were calibrated according to the groups indicated in the oxygen coefficients tables (see Table 5a and Table 5b).

Data Quality

The standard deviation of the differences between the CTD and rosette oxygen data for all stations scaled with precruise oxygen calibrations were significantly better (st.dev = 0.0478) for the secondary oxygen sensor than for the primary oxygen sensor (st. dev=0.251). Therefore, the secondary oxygen sensor data were used for the final WOCE format CTD data, after calibration coefficients were fine tuned according to station groupings.

Secondary Oxygen Sensor S/N 0072 data were used for final data.
Mfile: make_oxyfile was used to create file: S411_1oxy1_22.fit

Mfile: oxycal_sbe was used for the following fits:
.... fit stations [1:12 14:20] Bi Sl Pc Tc
.... fit stations [2:4] station dependent
.... fit stations [4:6] station dependent (use 4 from here)
.... fit stations [7:9] station dependent
.... fit stations [18:20] station dependent
.... fit stations [17] Bi Sl Pc Tc
.... fit stations [12 14:16] station dependent
.... fit stations [10:12] station dependent
.... apply station 2 cals to station 1
.... fit stations [21 22 13] station dependent

Table 5a. Best Fit Coefficients for Secondary Oxygen Sensor 0072 used for final data.

Bias	Slope	Pcor	Tcor	St. Dev	Sta Grp
-0.5726144088	0.4234828120	0.000127930172168	-0.0002115431		1
-0.5726144088	0.4234828120	0.000127930172168	-0.0002115431	0.0239	2
-0.5683230455	0.4234828120	0.000127930172168	-0.0002115431	0.0239	3
-0.6283194437	0.4423815197	0.000134943749922	-0.0017218854	0.0625	4
-0.6276397075	0.4423815197	0.000134943749922	-0.0017218854	0.0625	5
-0.6268874882	0.4423815197	0.000134943749922	-0.0017218854	0.0625	6
-0.6850799088	0.4461907939	0.000144766656777	-0.0002365892	0.0295	7
-0.6817238133	0.4461907939	0.000144766656777	-0.0002365892	0.0295	8
-0.6809565875	0.4461907939	0.000144766656777	-0.0002365892	0.0295	9
-0.5725798361	0.4322286467	0.0001288615944	-0.0049528542	0.0171	10
-0.5713845387	0.4322286467	0.0001288615944	-0.0049528542	0.0171	11
-0.5710739235	0.4322286467	0.0001288615944	-0.0049528542	0.0171	12
-0.6954931834	0.4387279902	0.000149311128913	0.0039752815	0.0269	14
-0.6967313233	0.4387279902	0.000149311128913	0.0039752815	0.0269	15
-0.6973475088	0.4387279902	0.000149311128913	0.0039752815	0.0269	16
-0.6606691345	0.4450826419	0.000143755908919	-0.0019999705	0.0177	17
-0.6327612058	0.4289647211	0.000141943048196	0.0020705685	0.041	18
-0.6294923537	0.4289647211	0.000141943048196	0.0020705685	0.041	19
-0.6256680104	0.4289647211	0.000141943048196	0.0020705685	0.041	20
-0.5439493264	0.4196083269	0.000129904179885	-0.0003132210	0.0476	21
-0.5413855261	0.4196083269	0.000129904179885	-0.0003132210	0.0476	22
-0.5352977415	0.4196083269	0.000129904179885	-0.0003132210	0.0476	13

Primary Oxygen Sensor 0820 data were NOT used for final data.

Mfile: make_oxyfile was used to create : P411_1oxy1_22.fit

Mfile: oxycal_sbe was used for the following fits:
.... fit stations [1:12 14:20] Bi Sl Pc Tc
.... fit stations [1:4] for Bi Sl (Pc Tc from above)
.... fit stations [4:6] station dependent (this sta 4 gets used)
.... fit stations [6:8] station dependent (this sta 6 gets used)
.... fit stations [12 14] station dependent
.... fit stations [9:12] station dependent (this sta 12 gets used)
.... fit stations [15:17] station dependent
.... fit stations [18:20] station dependent
.... fit stations [21 22 13] station dependent

Table 5b. Best Fit Coefficients for Primary Oxygen Sensor 0820 NOT used for final data.

Bias	Slope	Pcor	Tcor	St. Dev	Sta Grp
-0.3672556332	0.3593482924	0.000122440801591	0.0025456665	0.0689	1
-0.3672556332	0.3593482924	0.000122440801591	0.0025456665	0.0689	2
-0.3672556332	0.3593482924	0.000122440801591	0.0025456665	0.0689	3
-0.5209715503	0.4029685194	0.000144433835854	-0.0018350344	0.0771	4
-0.5073423674	0.4029685194	0.000144433835854	-0.0018350344	0.0771	5
-0.5454766577	0.4134342996	0.000153008278123	-0.0002700419	0.0408	6
-0.5431952700	0.4134342996	0.000153008278123	-0.0002700419	0.0408	7
-0.5278252772	0.4134342996	0.000153008278123	-0.0002700419	0.0408	8
-0.4015671377	0.4196809644	0.000132266783892	-0.0037812202	0.0547	9
-0.3981402922	0.4196809644	0.000132266783892	-0.0037812202	0.0547	10
-0.3849038263	0.4196809644	0.000132266783892	-0.0037812202	0.0547	11
-0.3814641393	0.4196809644	0.000132266783892	-0.0037812202	0.0547	12
-0.5309737323	0.4547548082	0.000147000696521	-0.0013193761	0.0326	14
-0.5817361448	0.4723009828	0.000155591090225	0.0020409357	0.048	15
-0.5806524350	0.4723009828	0.000155591090225	0.0020409357	0.048	16
-0.5779850498	0.4723009828	0.000155591090225	0.0020409357	0.048	17
-0.4549324894	0.4682253556	0.000134278812096	-0.0026820917	0.0381	18
-0.4496076227	0.4682253556	0.000134278812096	-0.0026820917	0.0381	19
-0.4433778767	0.4682253556	0.000134278812096	-0.0026820917	0.0381	20
-0.4481800076	0.4755319929	0.000133212971908	-0.0043977386	0.0567	21
-0.4452854198	0.4755319929	0.000133212971908	-0.0043977386	0.0567	22
-0.4384121750	0.4755319929	0.000133212971908	-0.0043977386	0.0567	13

II.1.f Other notable data acquisition/processing issues

At-sea logs were kept for CTD data acquisition. They include anything of note regarding each station: equipment changes, instrument behavior, equipment or operational problems. LADCP station logs were also kept for LADCP data collected during each station. An at-sea station event log was also kept during the cruise to point summarize notable information about each CTD station collected.

II.2 Salinity and Dissolved Oxygen Measurements

contributed by David Wellwood

II.2.a Summary

Water samples were collected from virtually every bottle during this cruise for the determination of salinity and dissolved oxygen. The primary purpose of these measurements were to accurately calibrate the sensors on the CTD.

II.2.b Salinity

Water was collected in 200 ml glass bottles. The bottles were rinsed twice, and then filled to the neck. After the samples reached the lab temperature of approximately 22°C, they were analyzed for salinity using a Guildline Autosal Model 8400B salinometer (WHOI #11, serial #59210). The salinometer's bath temperature was set to 24C and was standardized once a day using IAPSO Standard Seawater Batch P-143 (dated Feb.-2003). Conductivity readings were logged automatically to a computer, salinity was calculated and merged with the CTD data, and finally used to update the CTD calibrations. Accuracies of salinity measurements were ±0.002 psu.

II.2.c. Dissolved Oxygen

Measurements were made using a modified Winkler technique similar to that described by Strickland and Parsons (1972). Each seawater sample was collected in a 150 ml brown glass Tincture bottle. When reagents were added to the sample, iodine was liberated which is proportional to the dissolved oxygen in the sample. A carefully measured 50-ml aliquot was collected from the prepared oxygen sample and titrated for total iodine content. Titration was automated using a PC controller and a Metrohm Model 665 Dosimat buret. The titration endpoint was determined amperometrically using a dual plate platinum electrode, with a resolution better than 0.001 ml. Accuracy was about 0.02 ml/l, with a standard deviation of replicate samples of 0.005. This technique is described more thoroughly by Knapp et al (1990). Calculated oxygen was merged with the CTD data, and used to update the CTD calibrations. Standardization of the sodium thiosulphate titrant was performed daily.

III. References

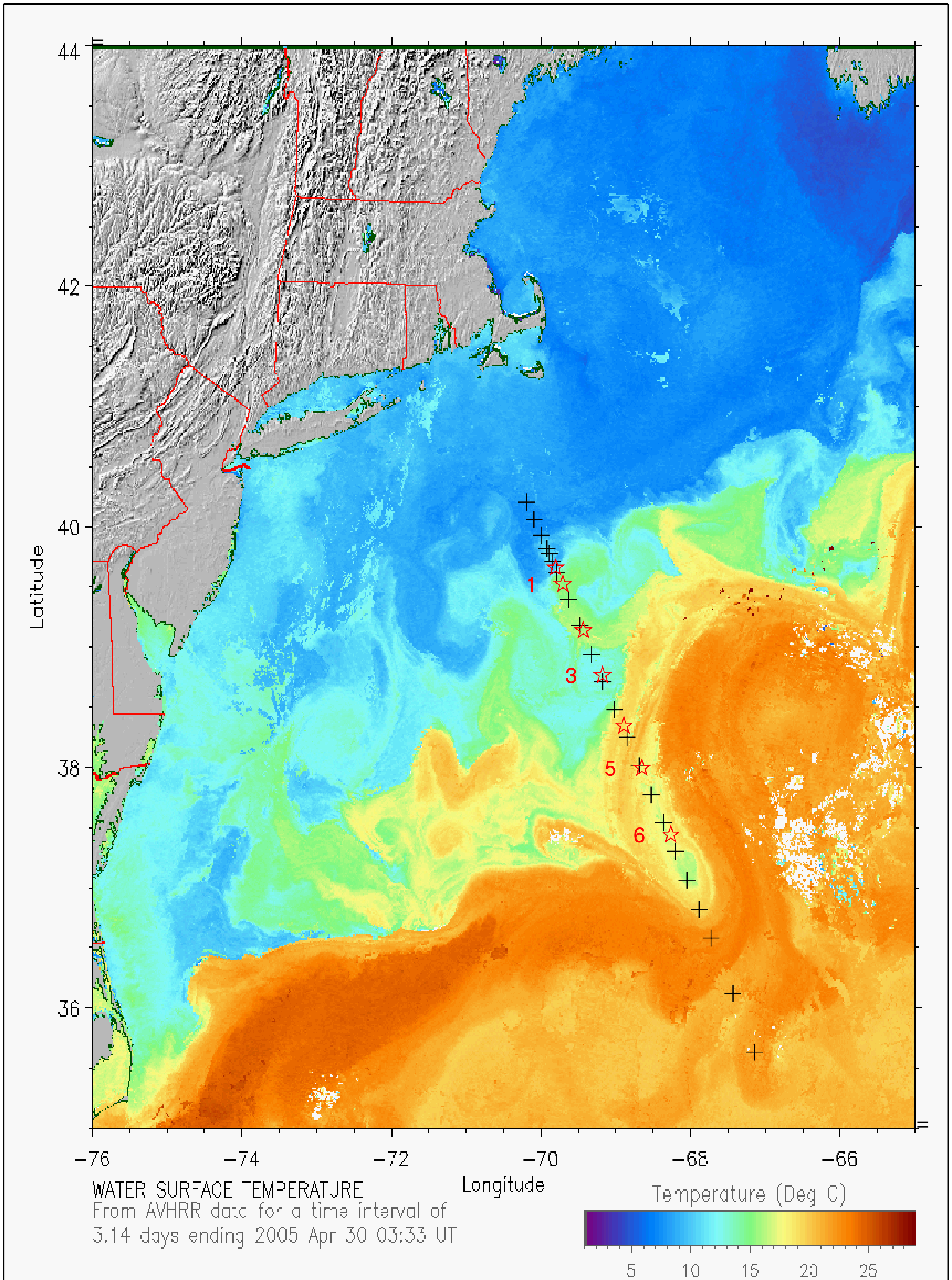
Knapp, G.P., M. Stalcup, and R.J. Stanley. 1990. Automated Oxygen Titration and Salinity Determination. WHOI Technical Report, WHOI-90-35, 25 pp.

Millard, R.C. and K. Yang. 1993. CTD Calibration and Processing Methods used at Woods Hole Oceanographic Institute. WHOI Technical Report, WHOI-93-44, 96 pp.

Owens, Brechner W. and Robert C. Millard, Jr. 1985. A New Algorithm for CTD Oxygen Calibrations. J. Phys. Oc. 15:621-631.

SeaBird Electronics, Inc. 2001. CTD Data Acquisition Software Seasoft Version 4.249 Manual.

Strickland, J.D.H. and T.R. Parsons. 1972. The Practical Handbook of Seawater Analyiss. Bulletin 167, Fisheries Research Board of Canada, 310 pp.


44
42
40
38
36
Latitude
1
3
5
6
−76
−74
−72
−70
−68
−66
Longitude
WATER SURFACE TEMPERATURE
From AVHRR data for a time interval of
3.14 days ending 2005 Apr 30 03:33 UT
Temperature (Deg C)
5
10
15
20
25